Retrospective on
THE FAILURE OF TETON DAM
Near Rexburg, Idaho
June 5, 1976

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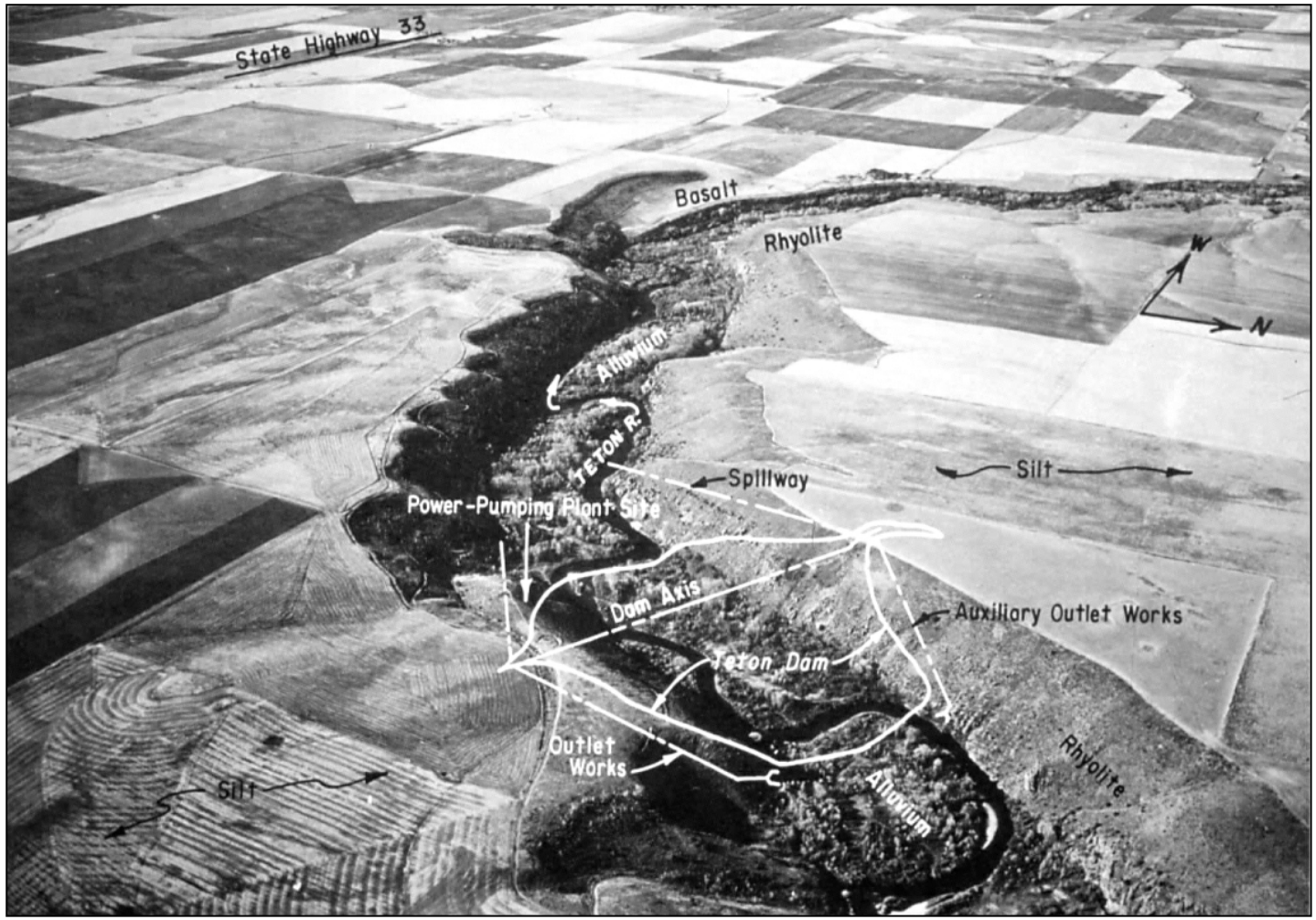

- **Teton Dam** was built on the Teton River, one of the principal features of the Teton Basin Project of the US Bureau of Reclamation funded in 1964. It was intended to supplement irrigation of 112,000 acres of farm land in the Upper Snake River Valley and generate 16,000 Kw of electricity. The plain above the gorge is covered by 30 feet of wind-blown loess.

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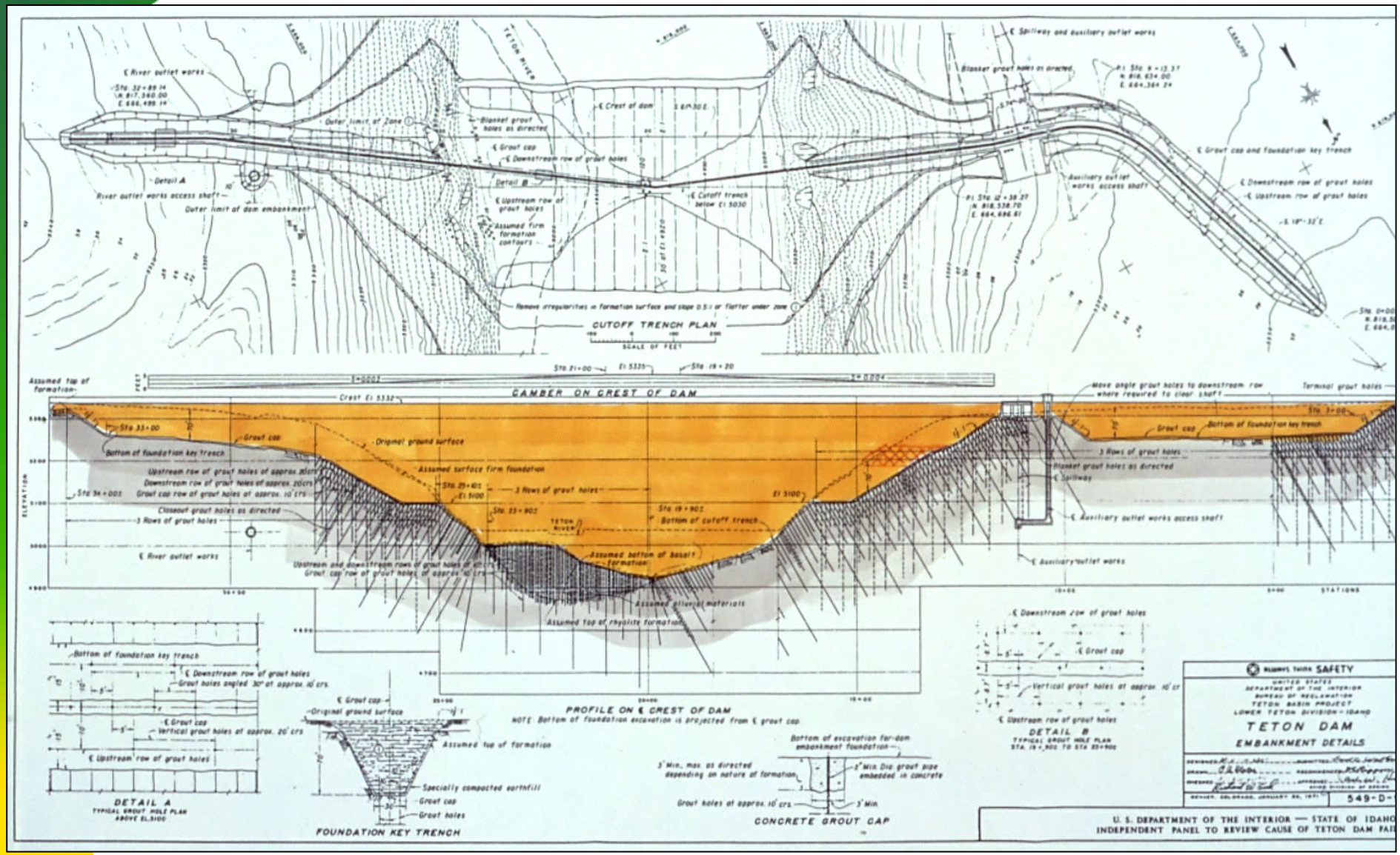

- **Teton Dam was designed with a triple line grout curtain beneath the earth embankment. But, the grout curtain ended up being built as a single-line because the grout take was more than double what had been allotted for the project.**

- **Teton Dam was designed as an earthfill embankment using wind blown loess as the principal fill material (seen here as light colored material) with river sand and gravel (shown as grey color), as the free draining material.**

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- **The dam's abutments were comprised of a perversely fractured welded ash-flow tuff (rhyolite), with beds of lapilli tuff and basalt. Large voids associated with volcanic fumaroles were detected during construction.**

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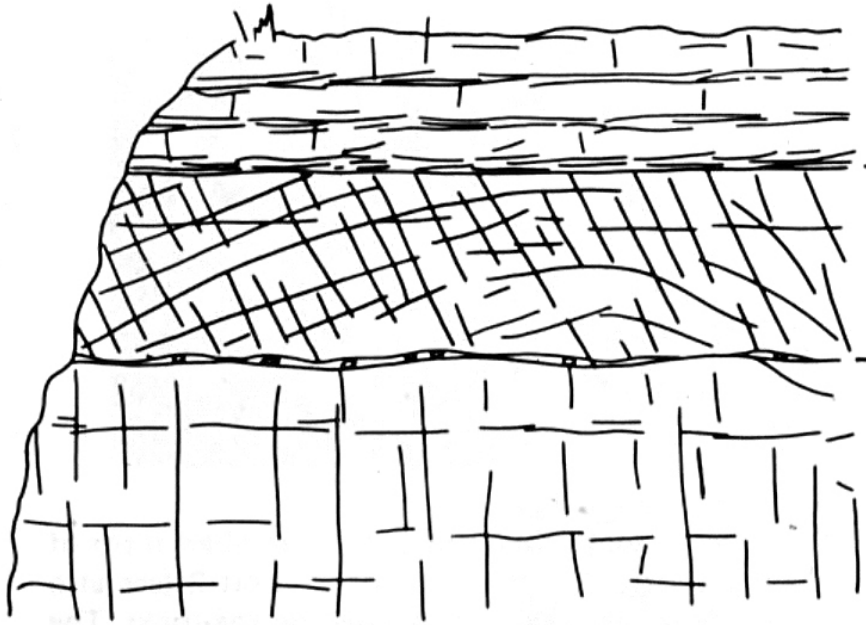

UNIT 1	Prominent and very abundant zones of low-angle platy joints
UNIT 2	Blocky, with closely to widely spaced moderately to steeply dippi (30° to 60°) joints dominant, some low-angle joints in upper part
UNIT 3	Blocky, massive, with moderately abundant near-vertical and low-angle joints

- **The three principal flow units identified in the dam abutments are shown here. Unit 2 was observed to be intensely jointed, with joint apertures of as much as 6 inches. Although many of the largest joints were filled with concrete slurry, no filter was placed between some of the open joints and the silty loess fill in the abutment keyways**

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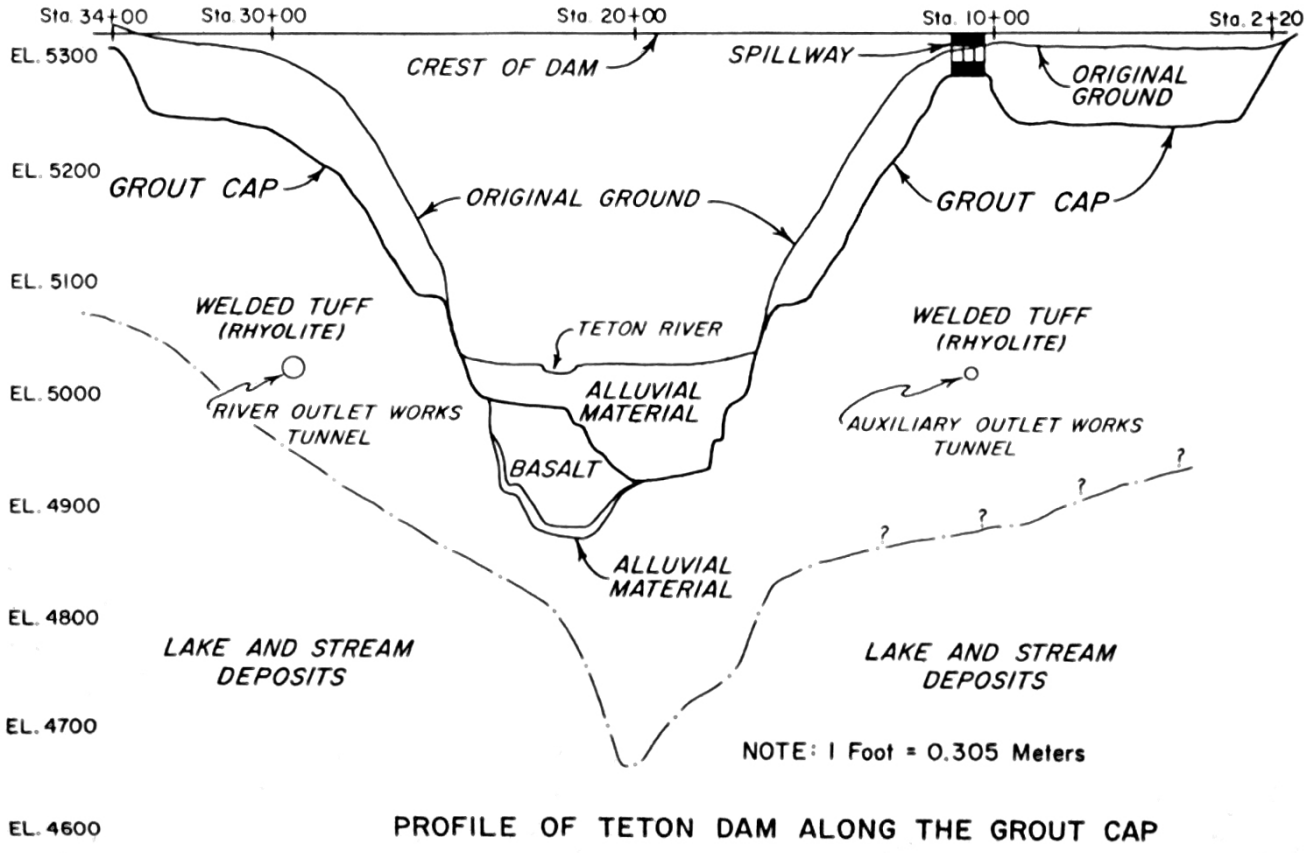

PROFILE OF TETON DAM ALONG THE GROUT CAP

- **The exposure of so much jointed and blocky rock led to a major design change, calling for the excavation of deep seepage cutoff trenches, or keyways, in each abutment. The grout curtain was extended to the depth indicated on this vertically exaggerated elevation view.**

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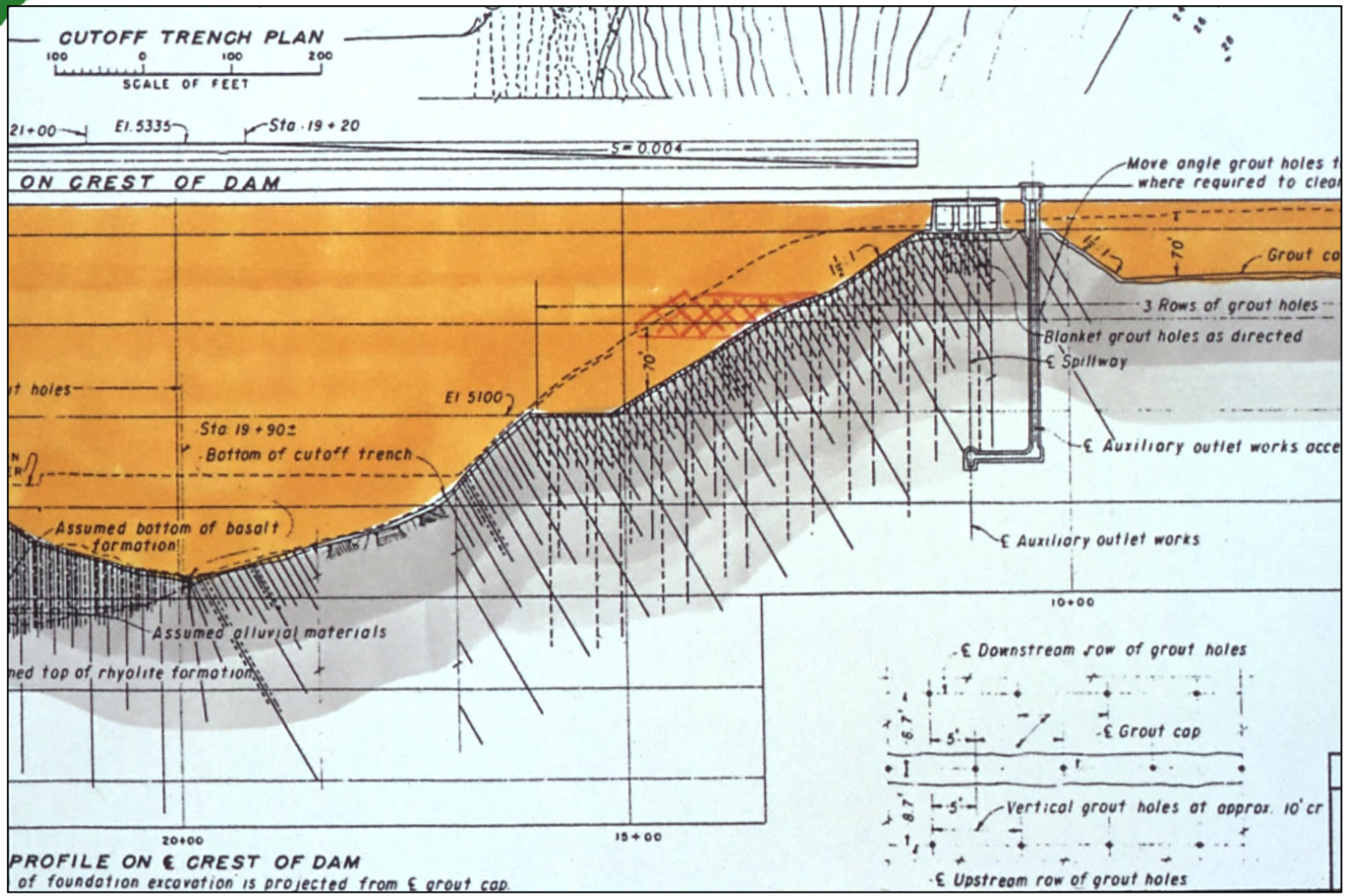
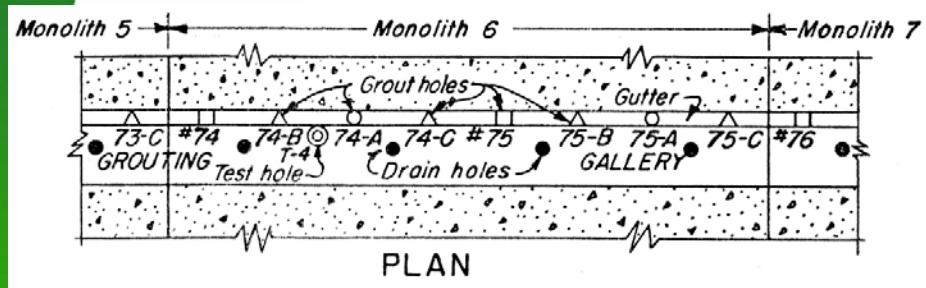
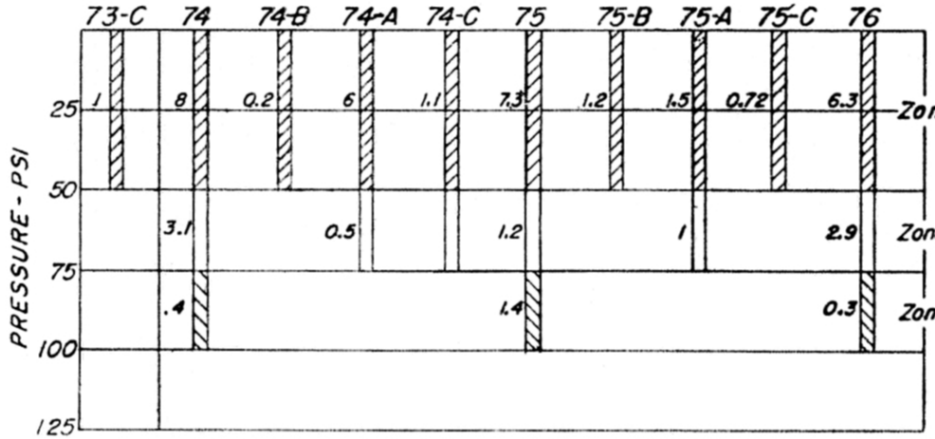


- **A single line of grout holes was utilized beneath the embankment because the grout takes were more than double what had been allotted for the project. The portion of the right keyway trench that failed is shown in red cross hatching.**

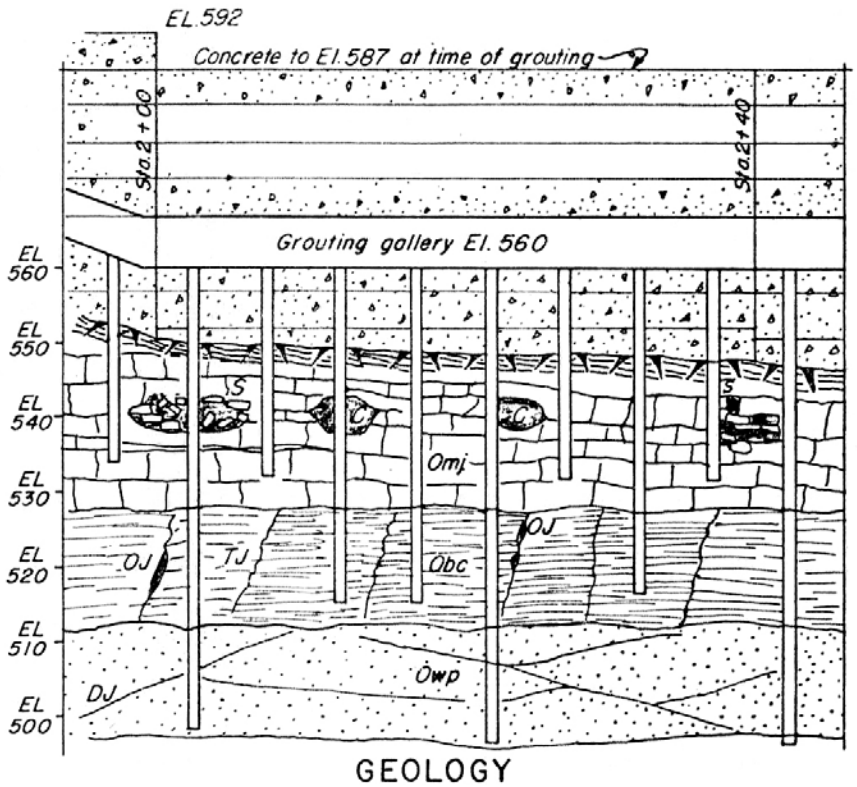
TYPICAL GROUTING PROGRAM



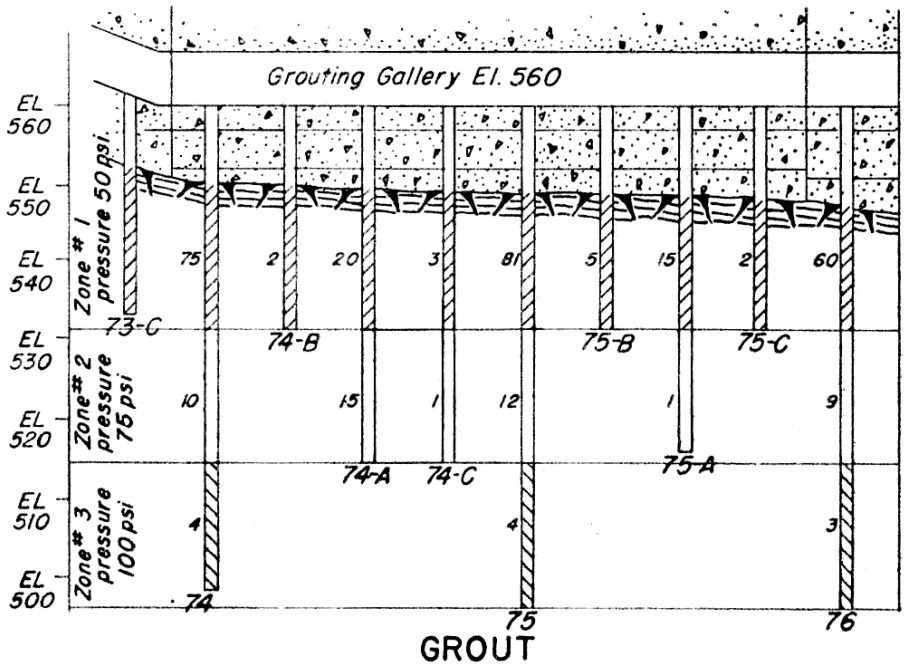
PLAN



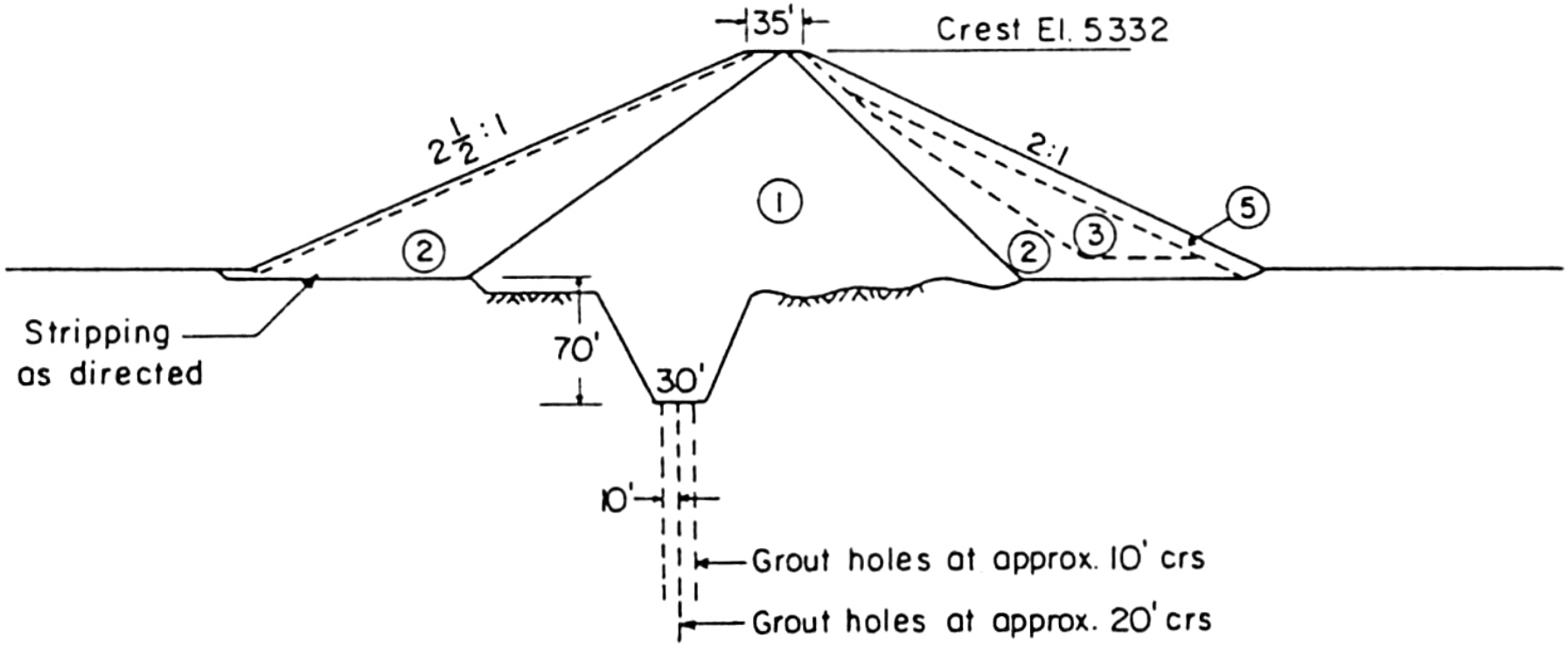
PRESSURE TEST



GEOLOGY



GROUT



- **The abutment keyway trenches were about 60 feet deep, excavated on 60 degree side slopes and 30 feet wide at their base. Although three lines of grout holes were shown in the amended design (seen here), these were not grouted sufficiently to create an effective seepage curtain.**

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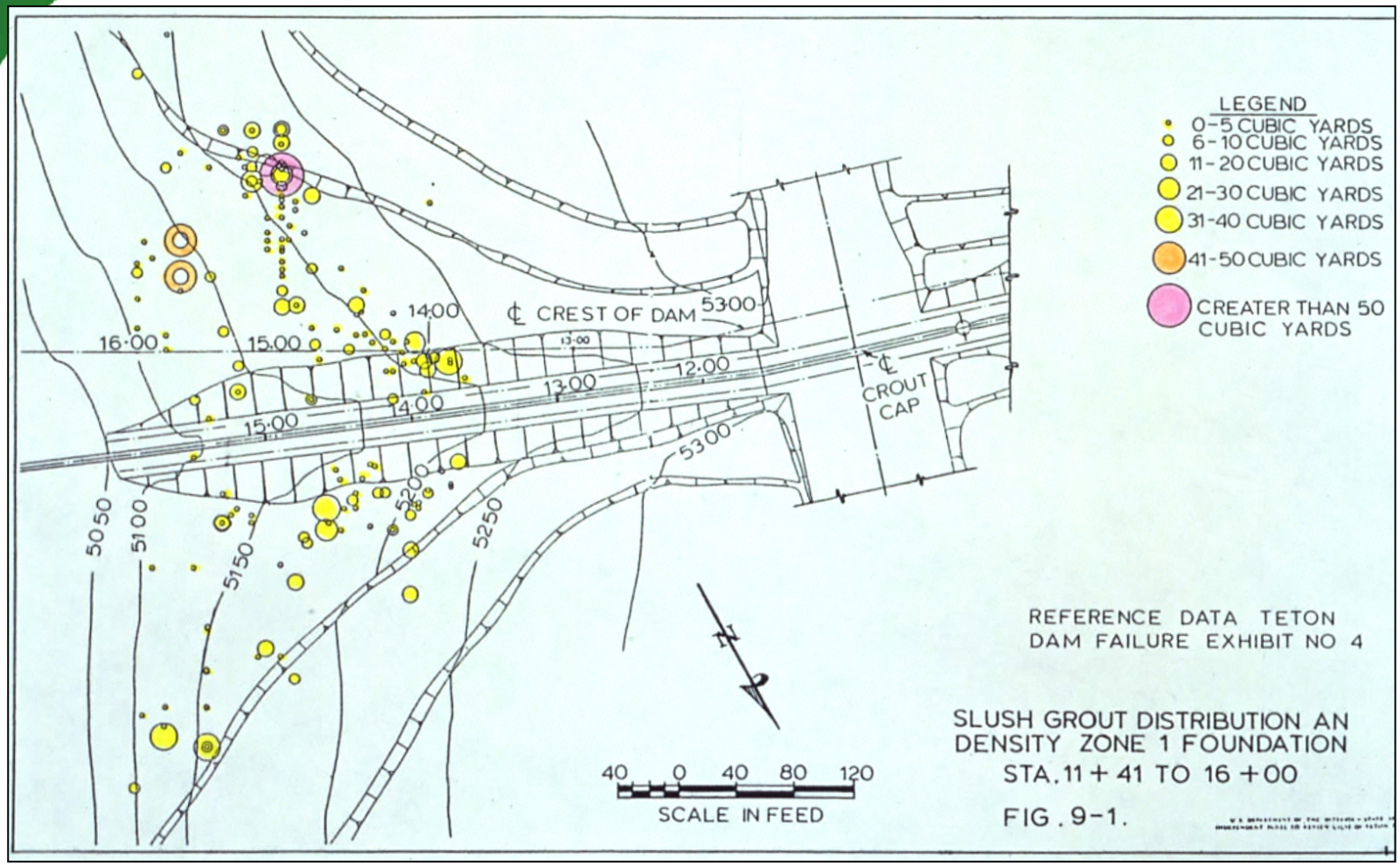

- **A grout test program was implemented which drilled 118,000 lineal feet of grout holes and injected 600,000 ft^3 of grout! This shows the volumes of slurry concrete applied to open fissures in the right abutment keyway area. Note the significantly high intake between Stations 14 and 15, where the seepage failure subsequently occurred.**

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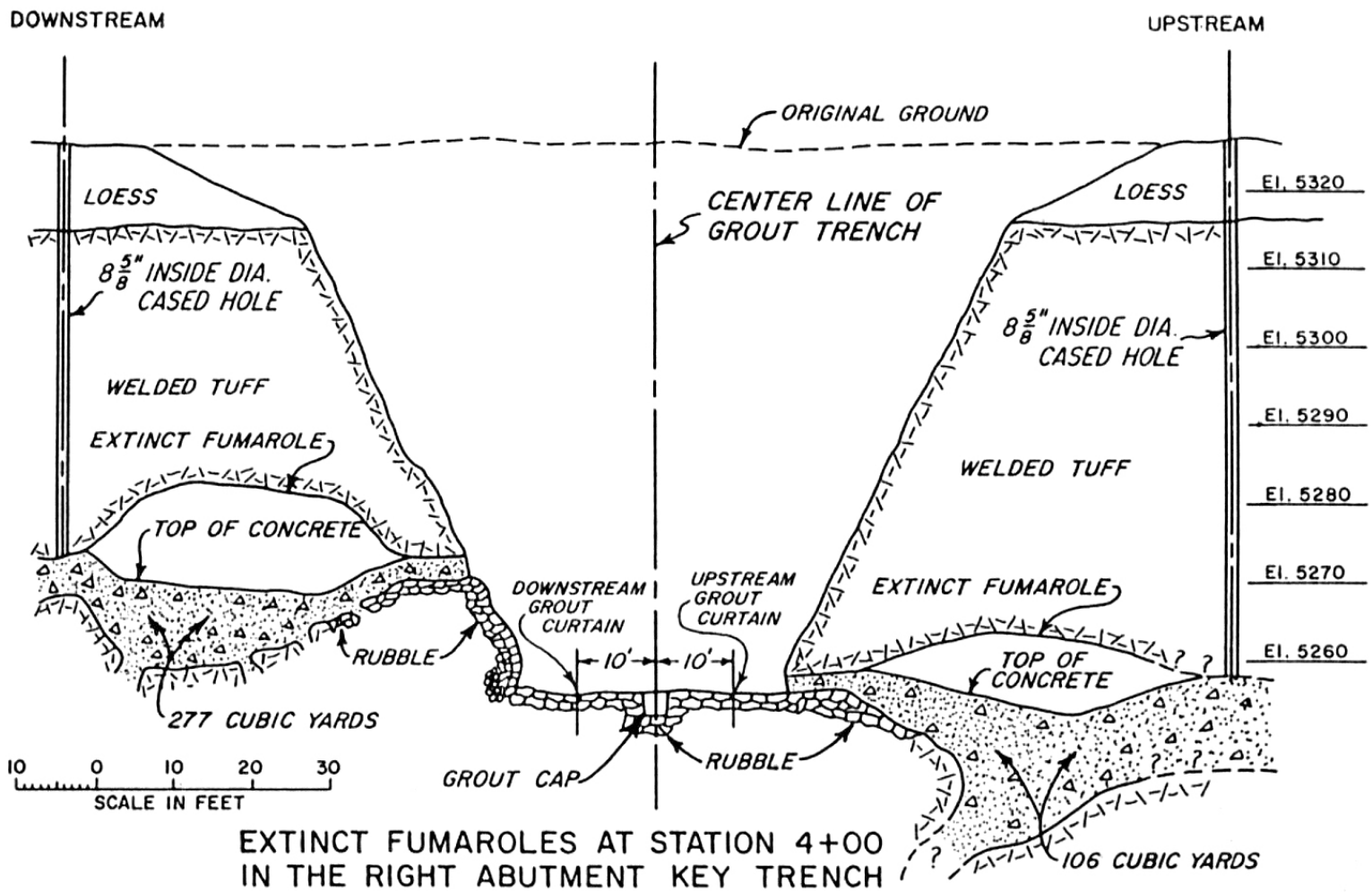

- **Section thru the Right Abutment keyway showing the enormity of the slurry concreting. One fissure was 6 feet wide! Most of the larger voids were thought to be "extinct volcanic fumaroles"**

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COMPACTION OF EMBANKMENT MATERIALS

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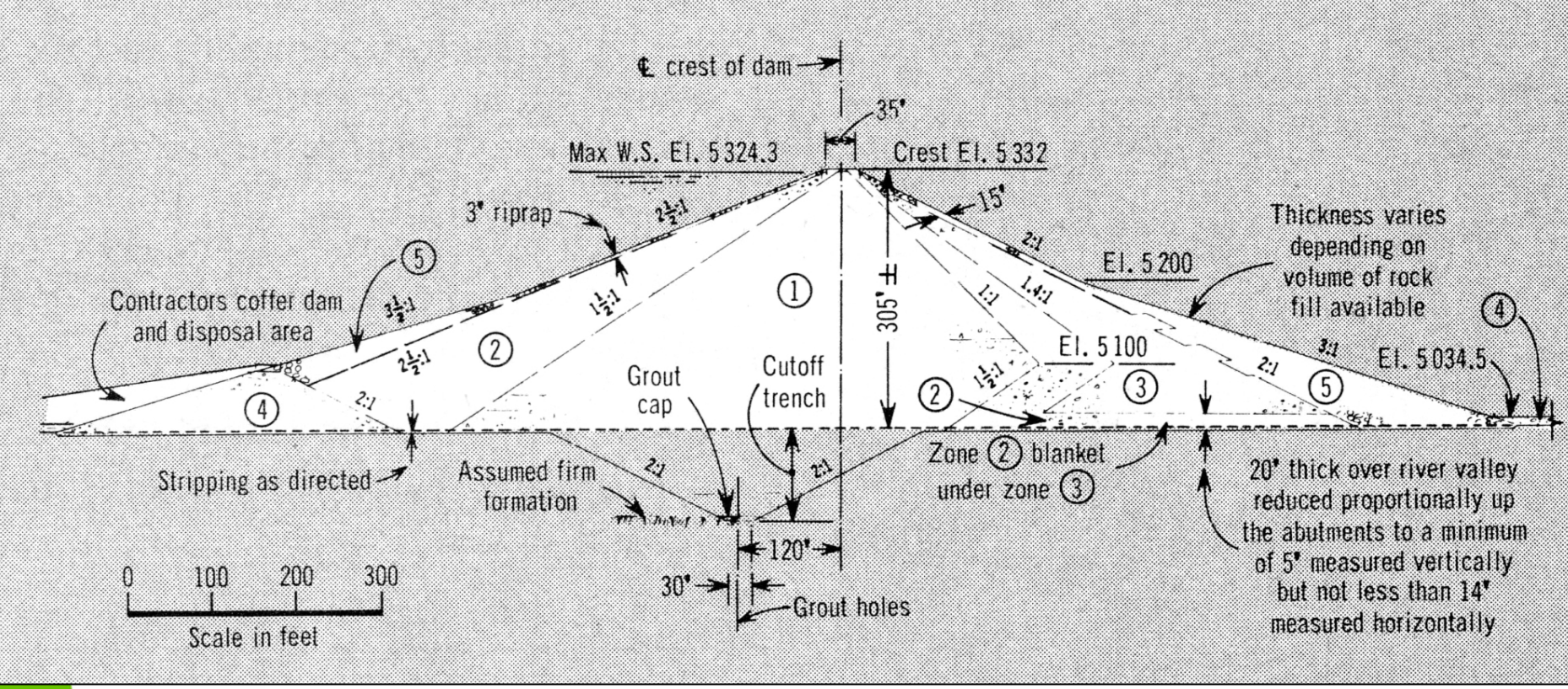

- **Design section through Teton Dam, showing the five principal fill zones. There were only three kinds of on-site materials: 1) wind blown loess (silt); 2) river gravels and sands; and 3) disaggregated rhyolite tuff from the abutment excavations**

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From May 29, 1975 Swing Shift Pass-On Book

May 29, 1975 (Continued)
Shift: swing (Continued)

"Left abutment, zone 1: Day shift's last lift was wet down, including abutment, with a 631B water wagon, scarified with a TD 15 dozer pulling a small set of disks, compacted with a 825B sheepsfoot roller. Fill against abutment was compacted with a TD-74 end dump loaded with zone 5 material and a pneumatic pogo stick. Two lifts were placed this shift by 631C scrapers. The above procedure was followed, except only the keyway was compacted by a 825B sheepsfoot roller and the fill against the abutment had not been compacted with a pneumatic pogo stick at the end of the shift. A test was taken. Elevation at end of shift: Sta. 25+20, 200' u/s = 5140; Sta. 26+40, 50' u/s = 5139; Sta. 25+50, 50' u/s = 5139; Sta. 25+20, 120' d/s = 5138."

"Right abutment, zone 1: Cleaning abutment for approximately 2 hours. Fill from day shift was compacted against abutment with a TD-74 end dump, loaded with zone 5 fill and a pneumatic pogo stick. Fill away from abutment was scarified by a TD 15 dozer pulling a small set of disks, then compacted with a 825B sheepsfoot roller. Two lifts were stockpiled from Sta. 14+96 to 15+32 and from 60' u/s to intersection of zone 1/2 as follows: previous fill wet down with a 631B water wagon, disked with a TD 15 dozer pulling a small set of disks, and compacted with a 825B sheepsfoot roller. Approximately a 6" lift was then graded off stockpile to against abutment after fill away from abutment had been wet down and scarified. A test on day shift fill was taken . . . Area, total length of d/s abutment was recompacted with a TD-74 end dump. After the 6" lift put in this shift, a retest was taken. Elevation at end of shift: Sta. 14+72, 45' u/s = 5151; Sta. 14+15, 45' u/s = 5152; Sta. 14+72, 68' d/s = 5149."

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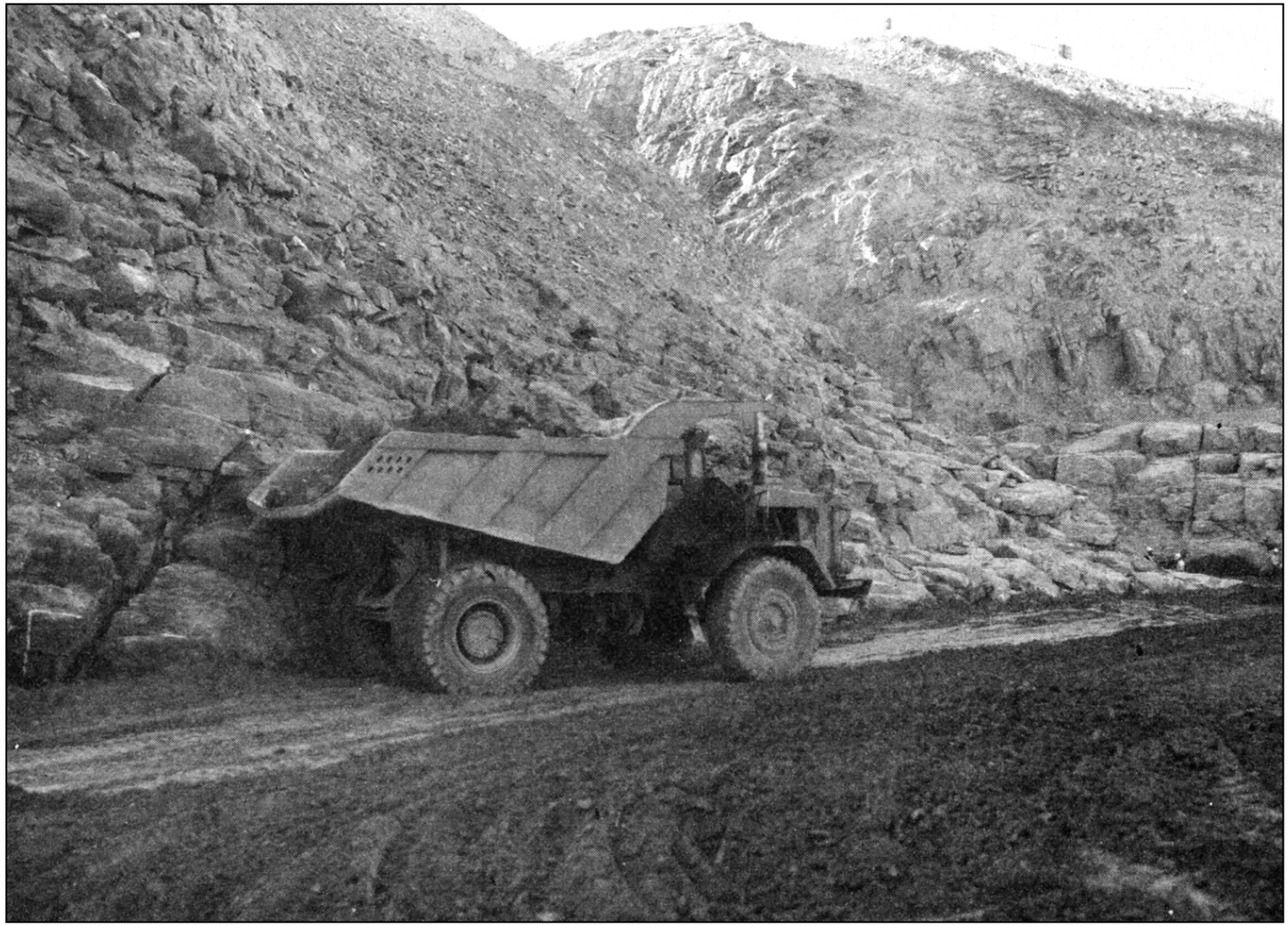

- **Euclid TD-74 dump trucks filled with Zone 5 rockfill were used to compact Zone 1 material (loess) up next to the abutments, as shown here. Right abutment keyway trench can be seen in background.**

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May 28, 1975 (Continued)
Shift: swing (Continued)

"Right abutment, zone 1: A 580B backhoe cleared loose material from base of abutment for approximately 2 hours on d/s side. Fill started on abutment this shift. Existing fill was wet down with a 631B water wagon. All fill and preparation was from 30' u/s to d/s zone 1/2 division line from abutment to approximately 20' out from abutment. Existing fill was then scarified with an TD 15 dozer pulling a small set of disks. Fill was then rolled with a 825B sheepsfoot roller. Fill was then disked with a TD 15 dozer pulling a small set of disks. The first lift was not put against abutment, but approximately 5' away. The second lift was also away from abutment. The third lift was placed against abutment. All fill was placed using 631C scrapers. The fill against abutment was compacted using a TD-74 end dump loaded with zone 5 fill material."

- **The construction records noted the beginning of fill placement in the right abutment keyway on May 28, 1975, during the swing shift. Note that fill placed against the rock was "compacted" with a TD-74 dump truck.**

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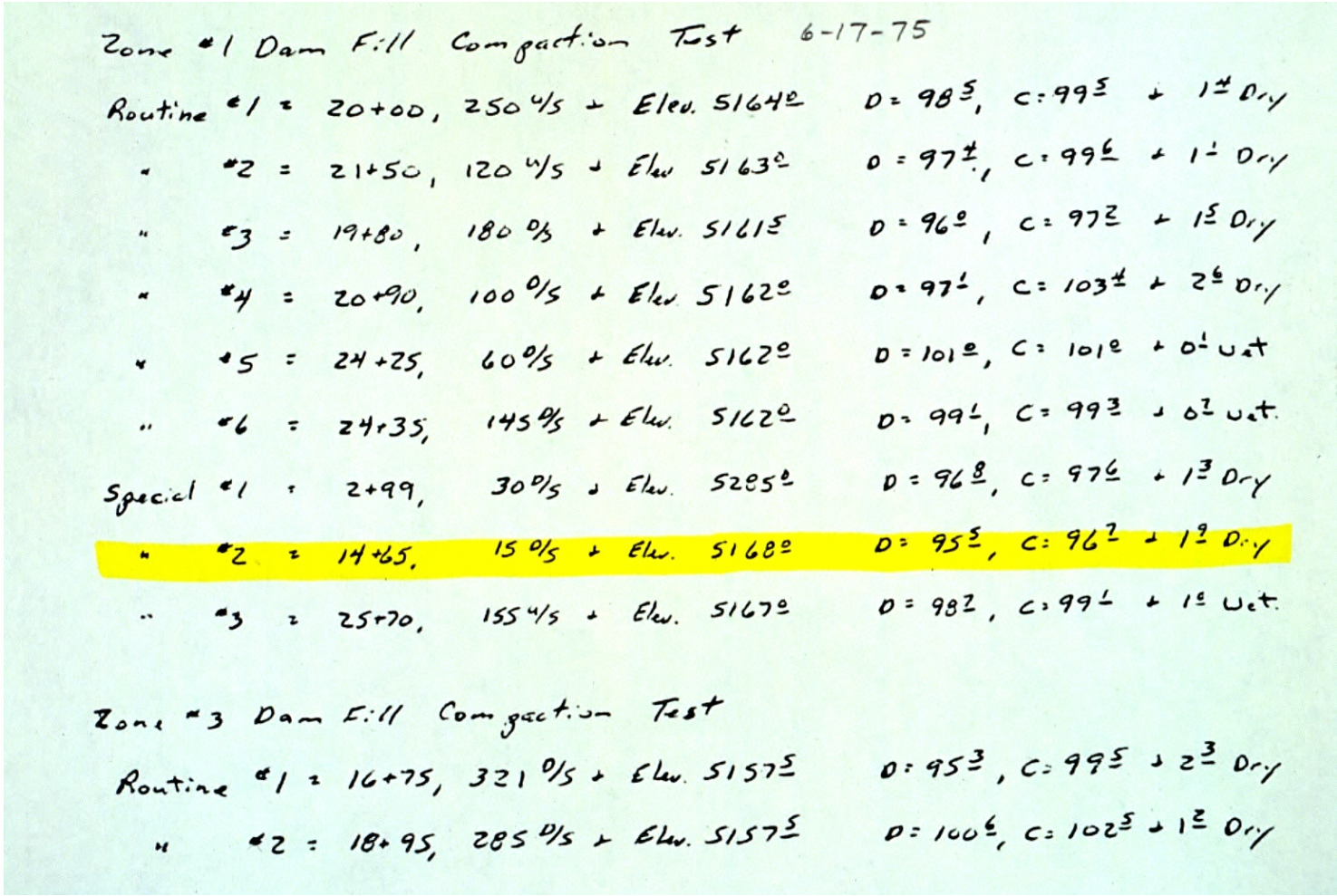

Zone #1 Dam Fill Compaction Test 6-17-75

Routine #1 = 20+00, 250 #/s + Elev. 5164± D = 98±, C = 99± + 1± Dry

" #2 = 21+50, 120 #/s + Elev. 5163± D = 97±, C = 99± + 1± Dry

" #3 = 19+80, 180 #/s + Elev. 5161± D = 96±, C = 97± + 1± Dry

" #4 = 20+90, 100 #/s + Elev. 5162± D = 97±, C = 103± + 2± Dry

" #5 = 24+25, 60 #/s + Elev. 5162± D = 101±, C = 101± + 0± wet

" #6 = 24+35, 145 #/s + Elev. 5162± D = 99±, C = 99± + 0± wet

Special #1 = 2+99, 30 #/s + Elev. 5285± D = 96±, C = 97± + 1± Dry

" #2 = 14+65, 15 #/s + Elev. 5168± D = 95±, C = 96± + 1± Dry

" #3 = 25+70, 155 #/s + Elev. 5167± D = 98±, C = 99± + 1± wet

Zone #3 Dam Fill Compaction Test

Routine #1 = 16+75, 321 #/s + Elev. 5157± D = 95±, C = 99± + 2± Dry

" #2 = 18+95, 285 #/s + Elev. 5157± D = 100±, C = 102± + 1± Dry

- **The pass-on book from June 17, 1975 notes achievement of 96% of Standard Proctor compaction and 2% dry of optimum moisture, in the right abutment keyway at elevation 5168 near Station 14+65. This is very close to where the hydraulic piping failure subsequently occurred.**

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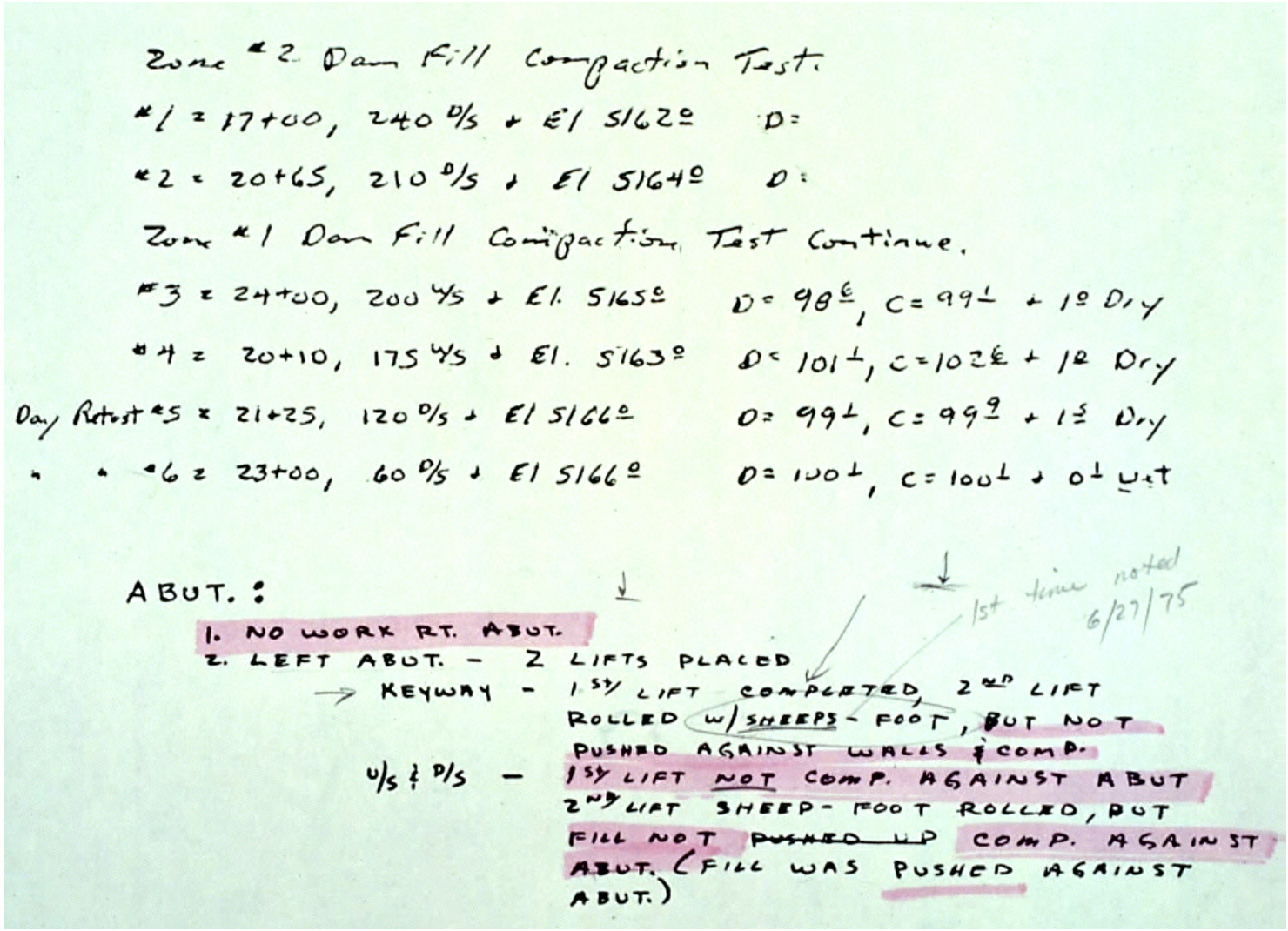

Zone #2 Dam Fill Compaction Test:

#1 = 17+00, 240 D/S + El 5162± D=

#2 = 20+65, 210 D/S + El 5164± D=

Zone #1 Dam Fill Compaction Test Continue.

#3 = 24+00, 200 U/S + El. 5165± D= 98±, C= 99± + 1± Dry

#4 = 20+10, 175 U/S + El. 5163± D= 101±, C= 102± + 1± Dry

Day Retest #5 = 21+25, 120 D/S + El 5166± D= 99±, C= 99± + 1± Dry

" " #6 = 23+00, 60 D/S + El 5166± D= 100±, C= 100± + 0± Wet

ABUT.:

1. NO WORK RT. ABUT.
2. LEFT ABUT. – 2 LIFTS PLACED
   → KEYWAY – 1ST LIFT COMPLETED, 2ND LIFT ROLLED W/ SHEEPS-FOOT, BUT NOT PUSHED AGAINST WALLS & COMP.
   U/S & D/S – 1ST LIFT NOT COMP. AGAINST ABUT 2ND LIFT SHEEP-FOOT ROLLED, BUT FILL NOT ~~PUSHED UP~~ COMP. AGAINST ABUT. (FILL WAS PUSHED AGAINST ABUT.)

1st time noted 6/27/75

- **The June 27, 1975 pass-on log notes that the decision was made to change to a CAT 825B sheepsfoot compactor in the abutment keyways because of failing compaction tests**

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- **CAT 826B self-propelled sheepfoot compactor, similar to that employed in the abutment keyways after June 27th. Their compactive effort is between 175 and 475 psi, depending on the type of wheel used. A pad roller is at left (175 psi) and sheepsfoot at center (475 psi).**

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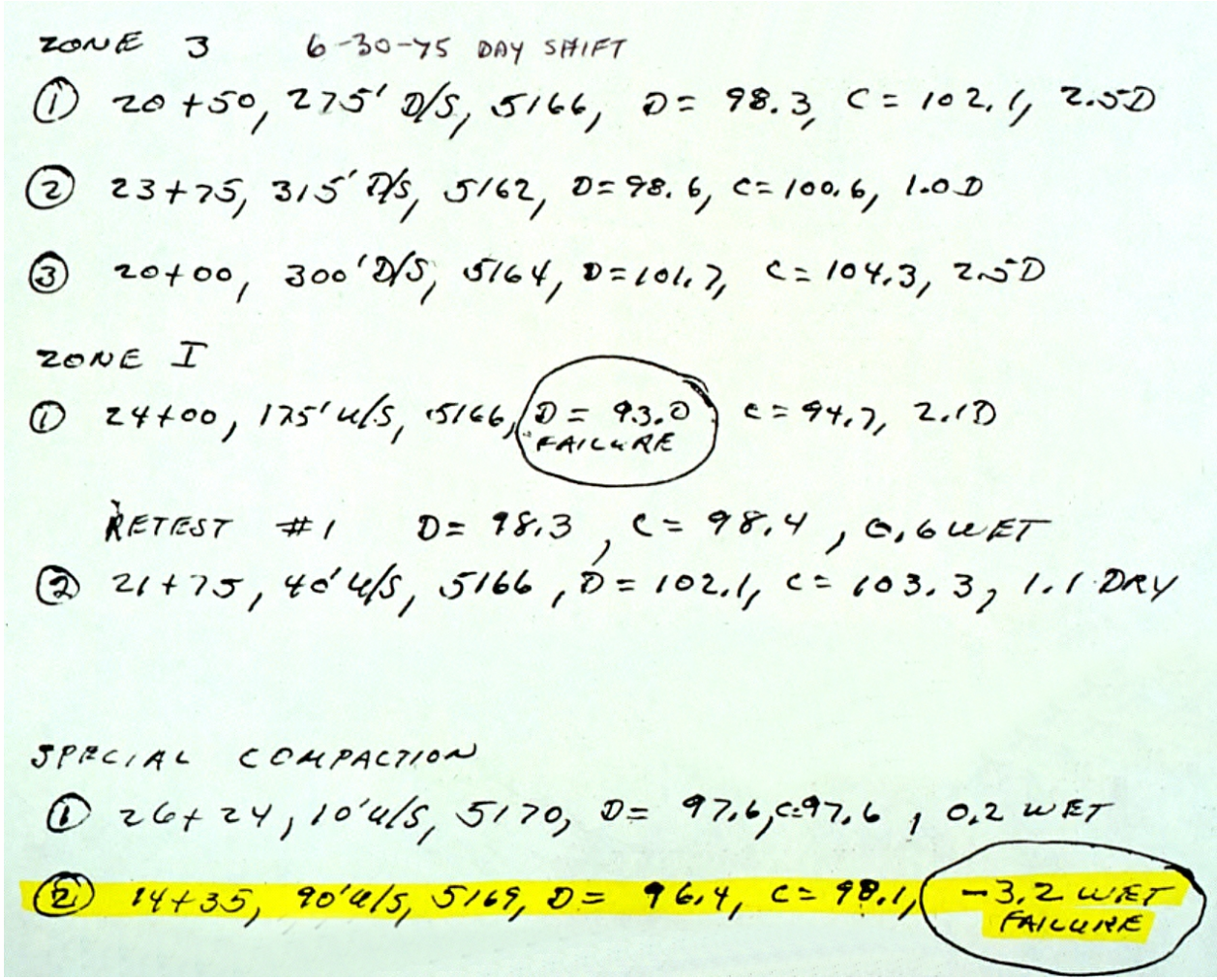

- **The pass-on book recorded a compaction test failure in the right abutment keyway on June 30th, because of excessive moisture. These are Standard Proctor (ASTM D698) tests.**

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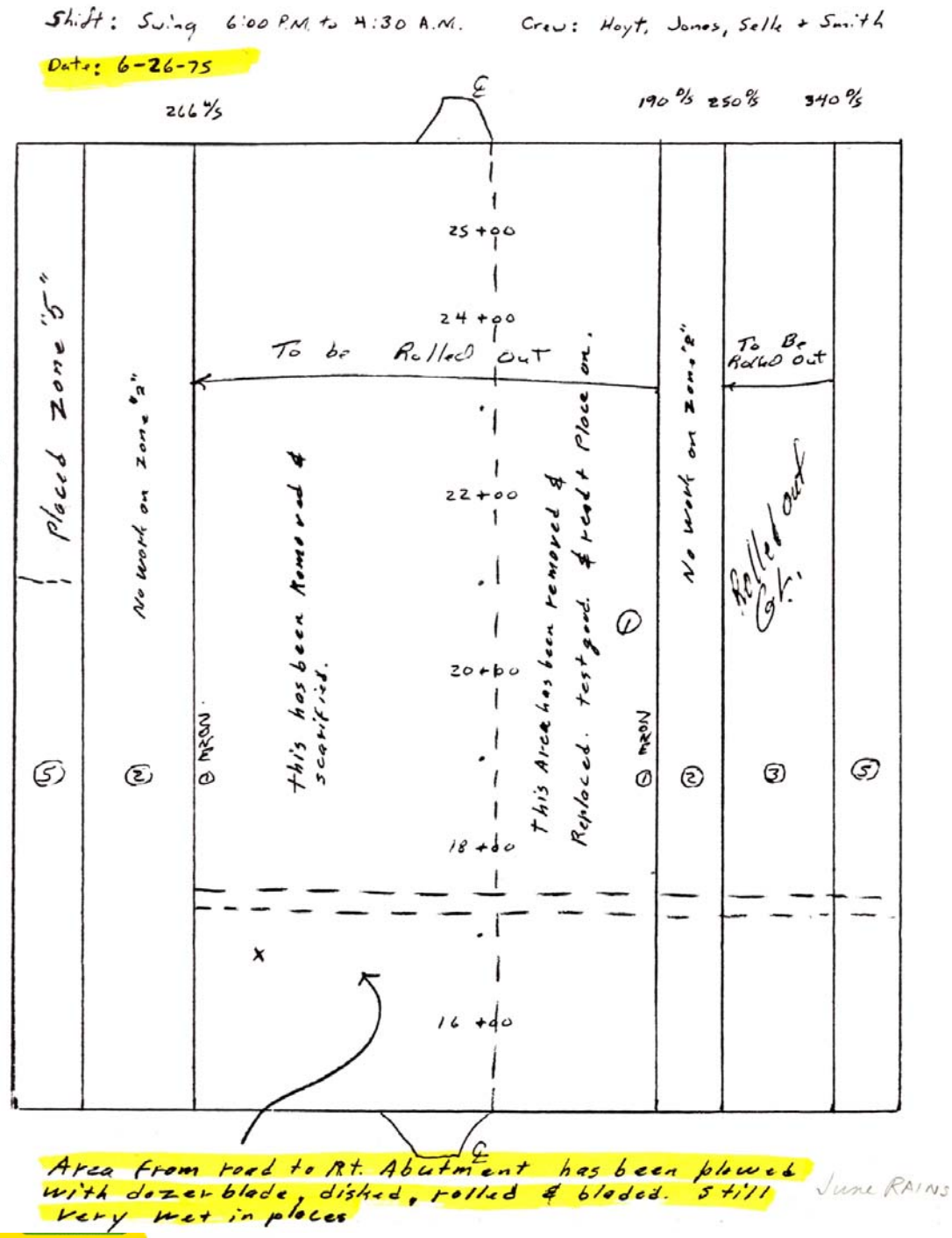
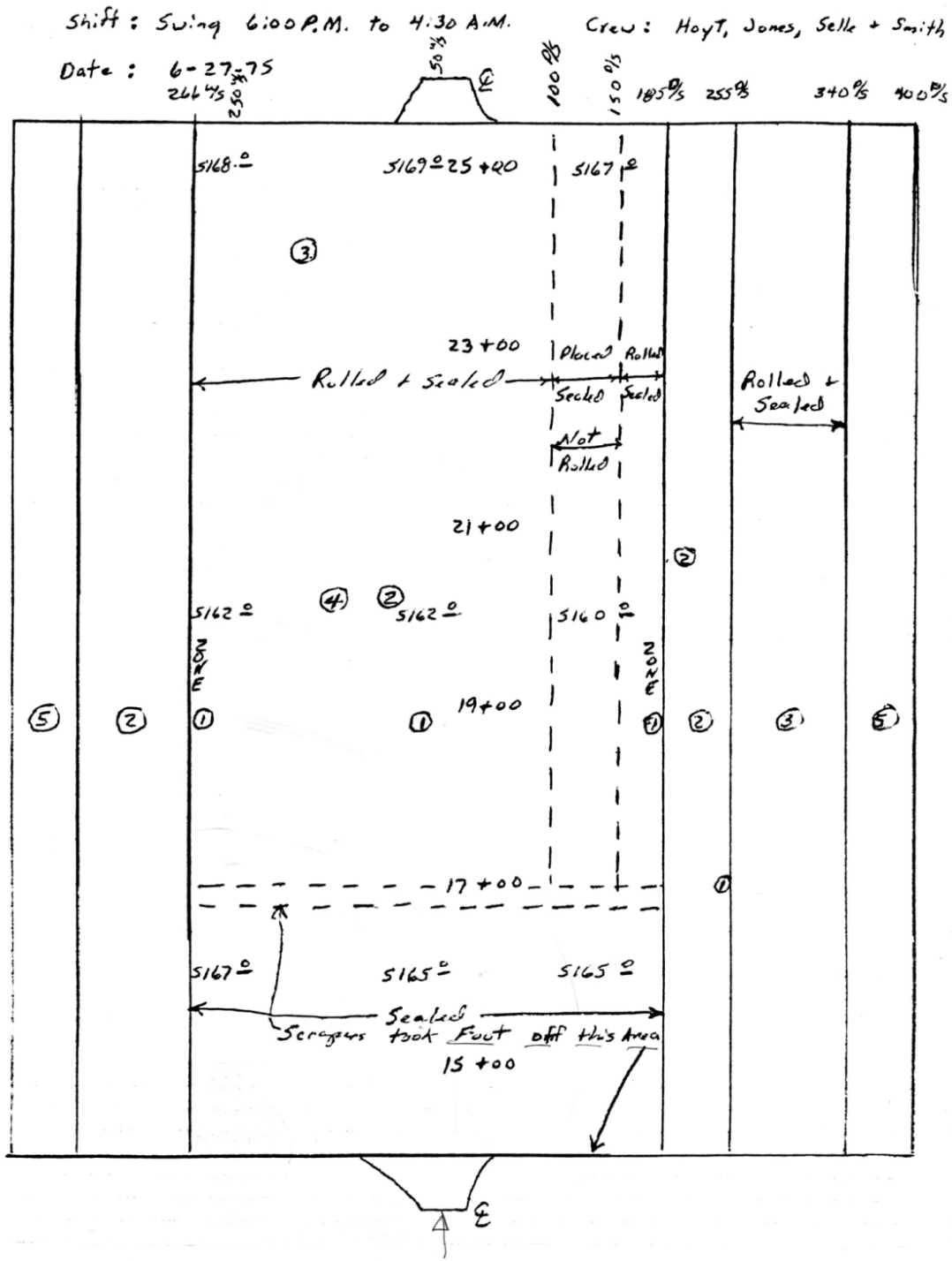
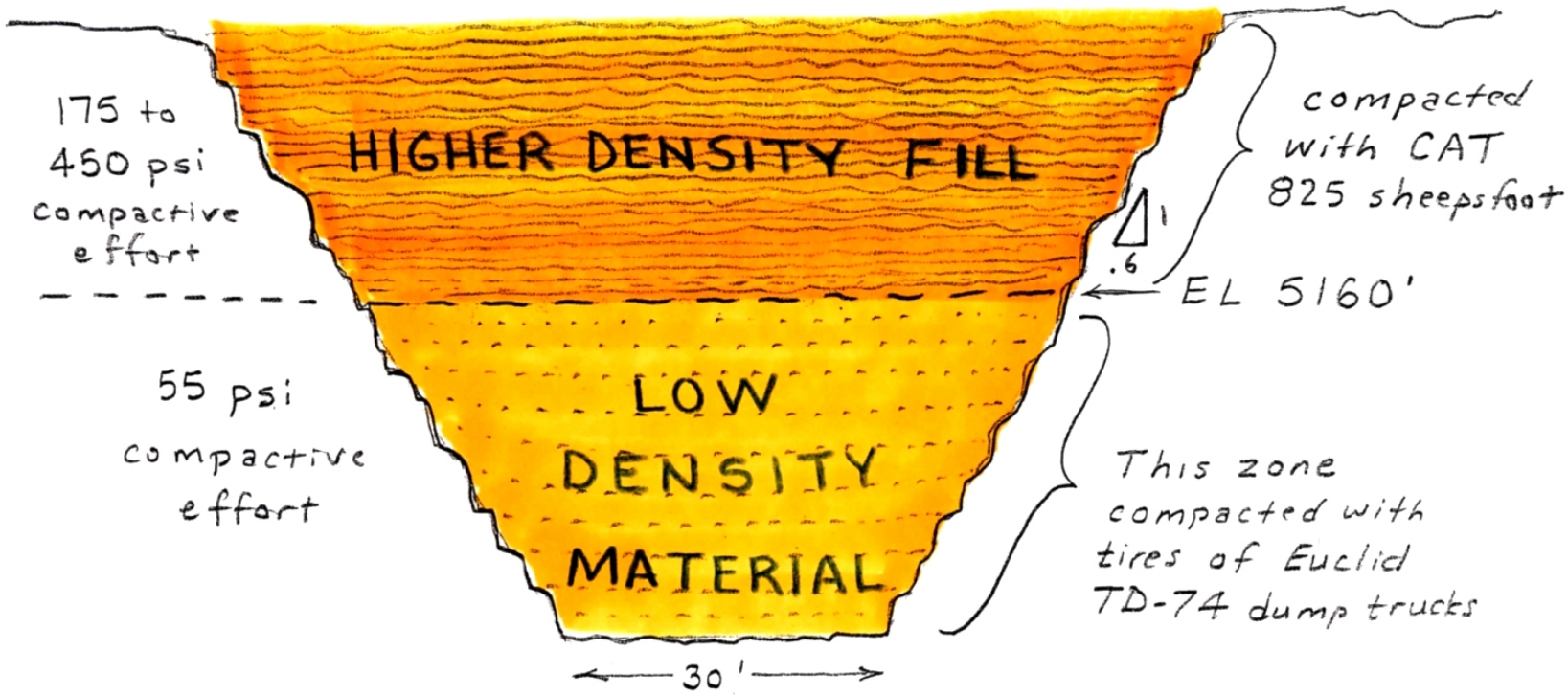


- **Embankment plan from pass-on book during swing shift on June 26, 1975**
- **It indicates that material between Station 17+50 and the right abutment keyway had to be plowed with a dozer blade, and striped, disked, rolled and bladed because it was “very wet in places” from June 1975 rains.**



- **Embankment plan in pass-on book for swing shift on June 27, 1975 showing right abutment area near elevation 5165 feet**
- **Scrappers were ordered to remove a foot of wet material from this area**



SECTION THRU ABUTMENT KEYWAY
FILLED WITH COMPACTED ZONE 1 FILL

- **By changing from the TD-74 dump trucks to the CAT 826, the compactive effort was increased more than five-fold.**
- **A much stiffer wedge of fill was thereby created above lower density fill in the base of the keyway trench**

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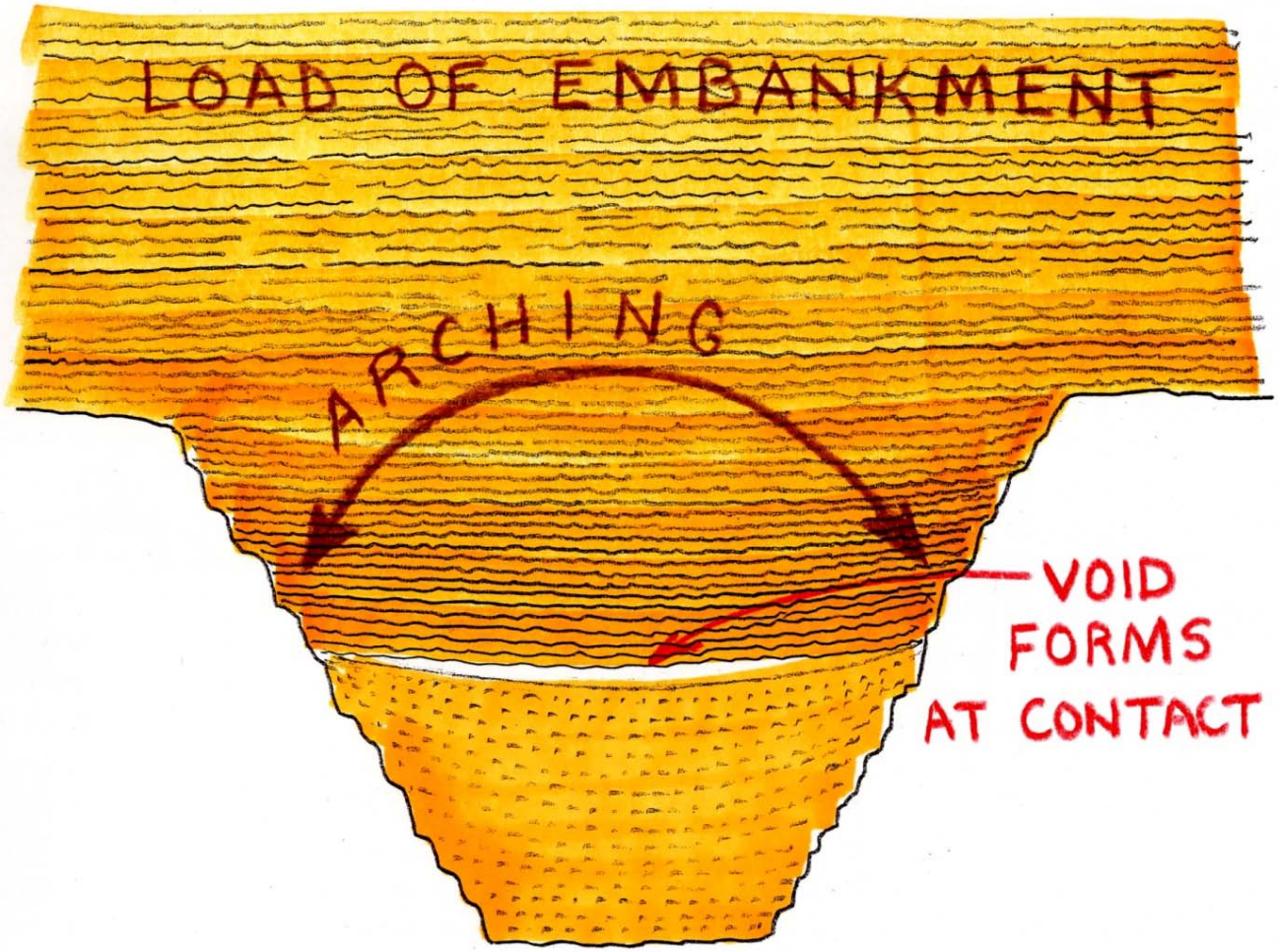

- When the reservoir filled, the compacted loess would have been wetted. Low density loess compacted dry-of-optimum moisture content would be more susceptible to hydrocompaction.
- Hydrocompaction-induced settlement may have contributed to the formation of voids and subsequent hydraulic fracturing between fill of contrasting density, as sketched here.

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FAILURE SEQUENCE

On June 5, 1976

- Newly-completed Teton Dam as it appeared in mid-May 1976, as the reservoir was filling at the rate of 3 feet per day. The rate of filling is usually limited to no more than 1 foot per day. This view is looking towards right abutment

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- **Leakage was initially noted around 7 AM on Saturday June 5, 1976. This view shows a dozer being sent down to fill in the hole at elevation 5200 around 10:45 AM**

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- **The dozer is lost in the expanding hole, around 11:20 AM on June 5th. Note turbid nature of outflow along the abutment**

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- Rapidly deteriorating situation as it appeared around 11:30 AM. A massive hole has developed in the downstream face of the embankment and is migrating upward

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- **The hole continues to enlarge and rise toward the crest of the right abutment. This is about 11:50 AM**

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- **Dam crest beginning to breach at 11:55 AM on Saturday June 5, 1976. Note increasing discharge.**

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- **Maximum flood discharge emanating from gap in dam's right abutment, just after noon on June 5th, 1976**

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- **The final breaching is filmed from a helicopter that was sent out to warn people downstream of the imminent failure. Amazingly, one of two men fishing a half mile downstream survived!**

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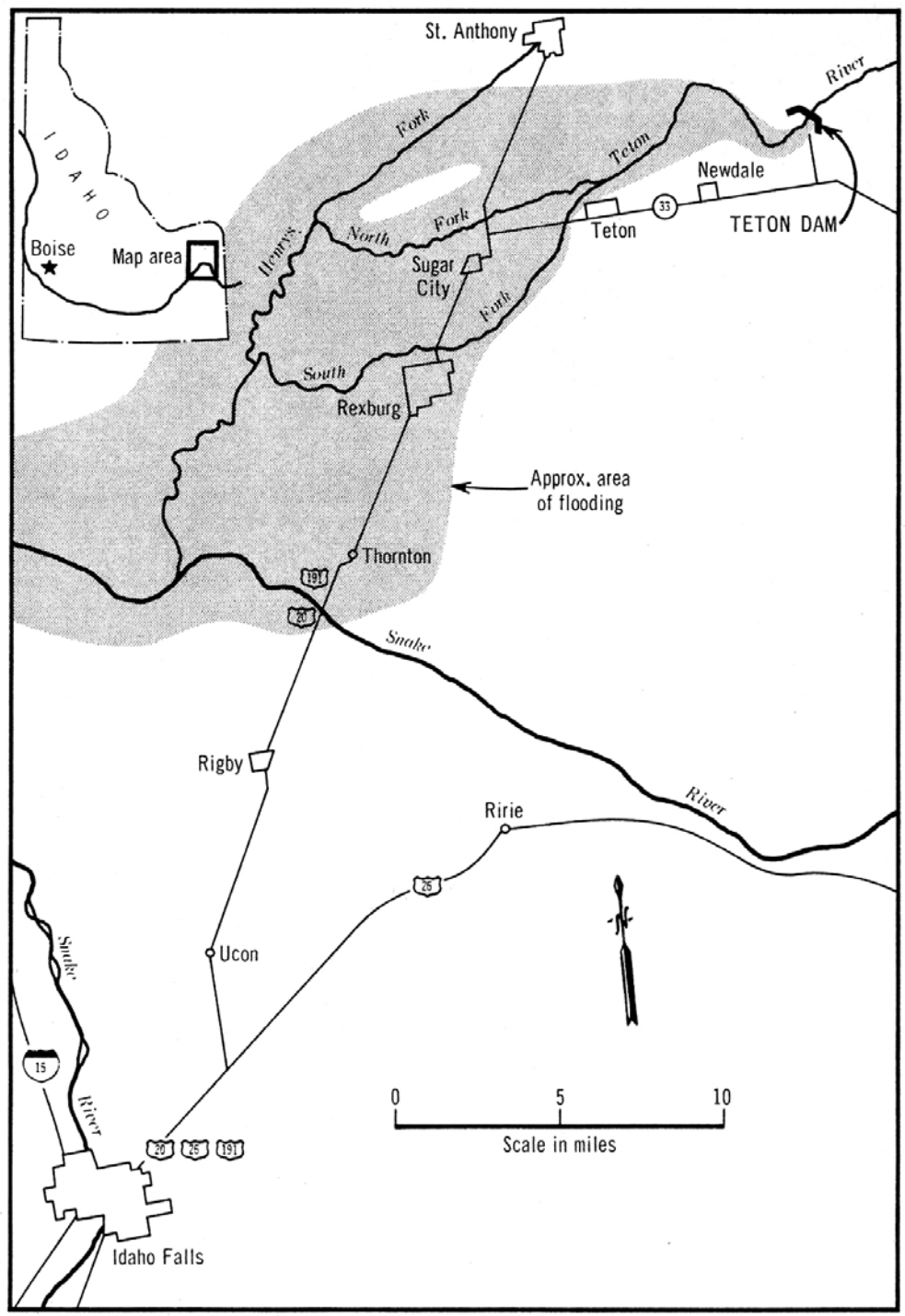
A

$1 BILLON

DOLLAR

FLOOD



- **The flood inundated the towns of Sugar City and Rexburg, only killing 6 because of the advance warning**
- **The loss ended up costing the federal government close to $1 billion dollars**
- **At 350 feet high, Teton was the highest dam to ever fail**
- **It's untimely failure signaled an end to the era of big dam building in America**

- View looking upstream the day after the failure. The piping failure initiated on the right abutment, between elevations 5190 and 5230.

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- Telephoto view of crest of right abutment, showing remains of the right abutment keyway, crest embankment and spillway gates.

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POST FAILURE ANALYSIS

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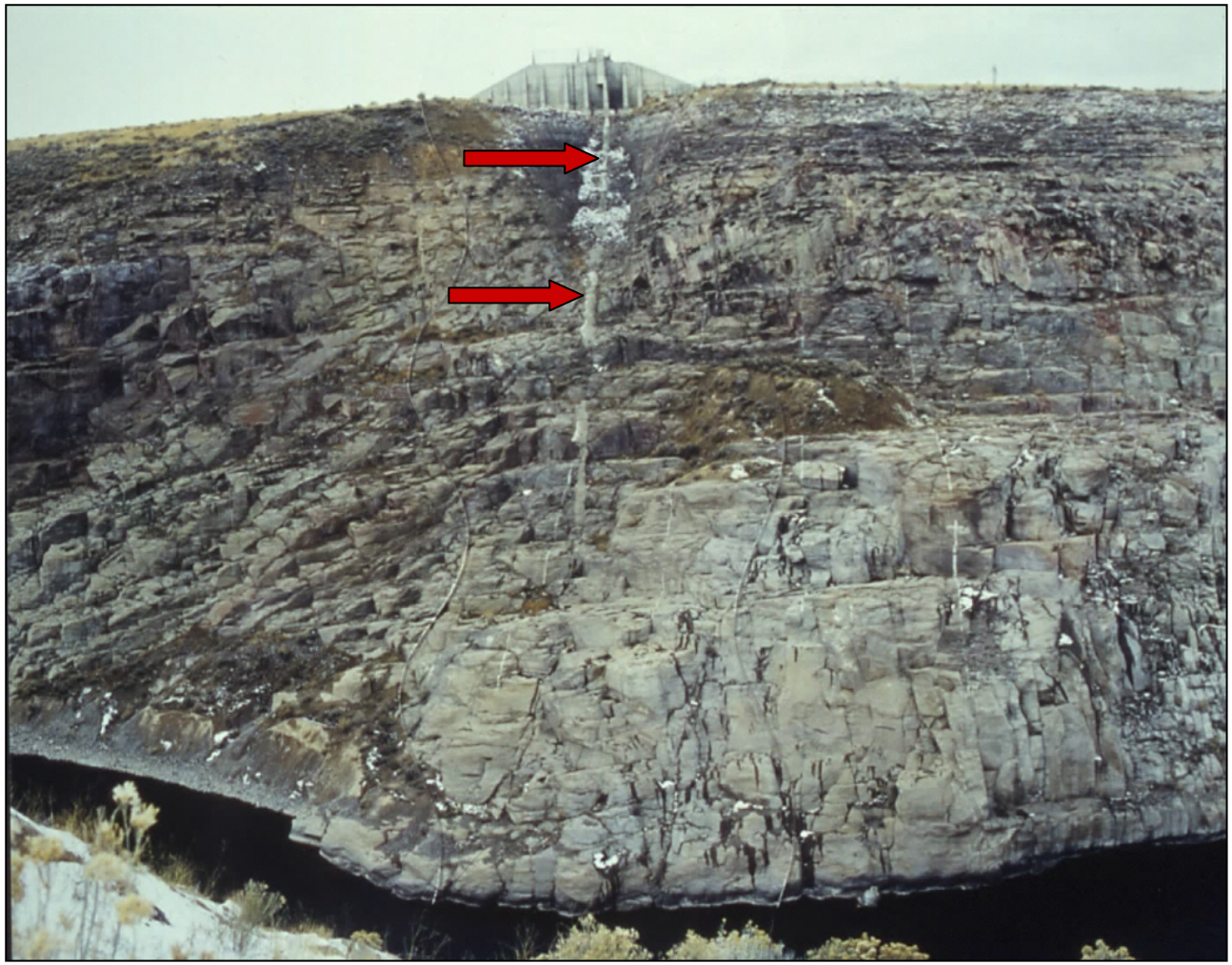

- **Looking at the right abutment and the remains of the grout cap (arrows). The 60 foot deep V-notched keyway was swept away during the flood**

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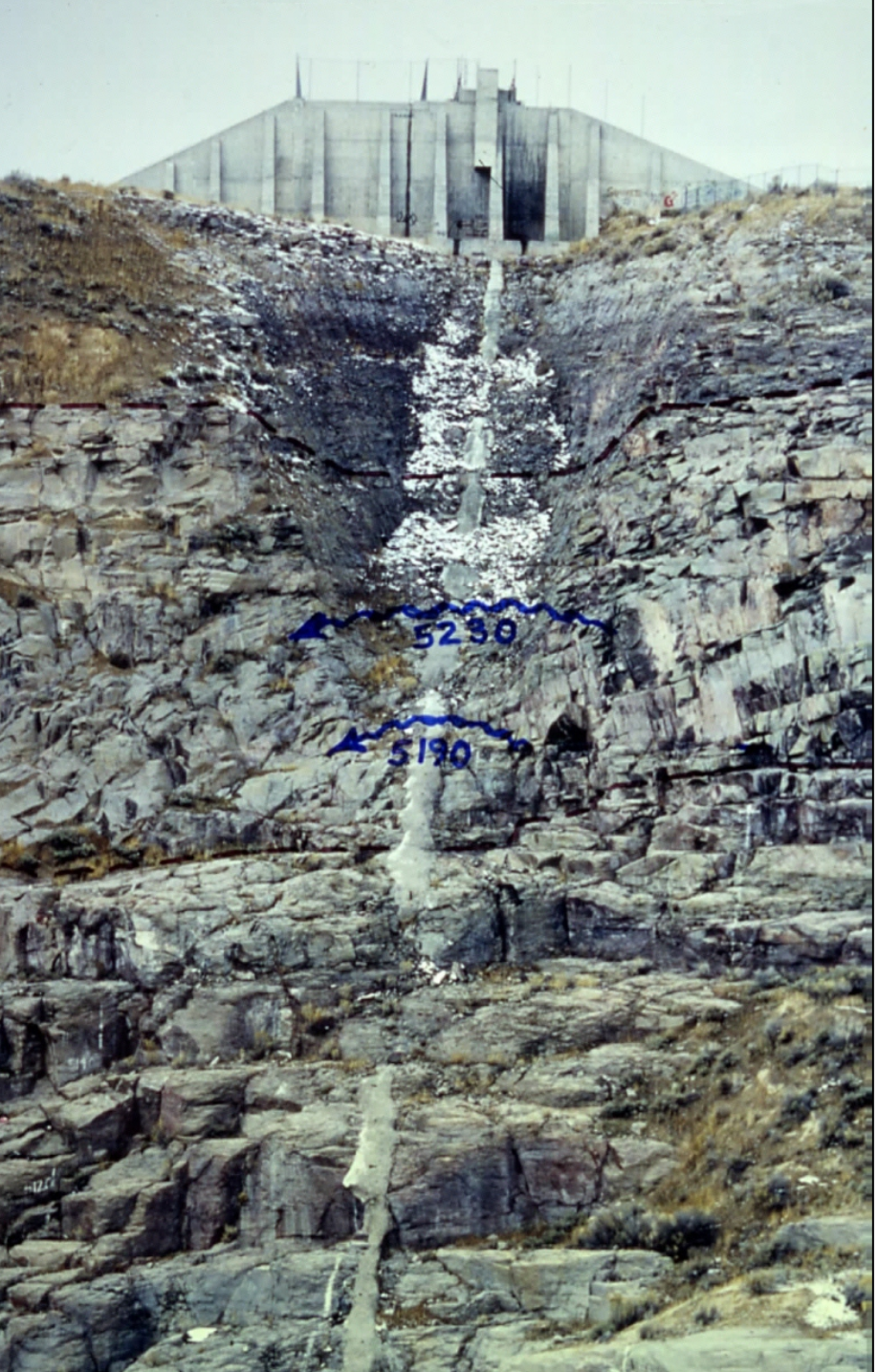
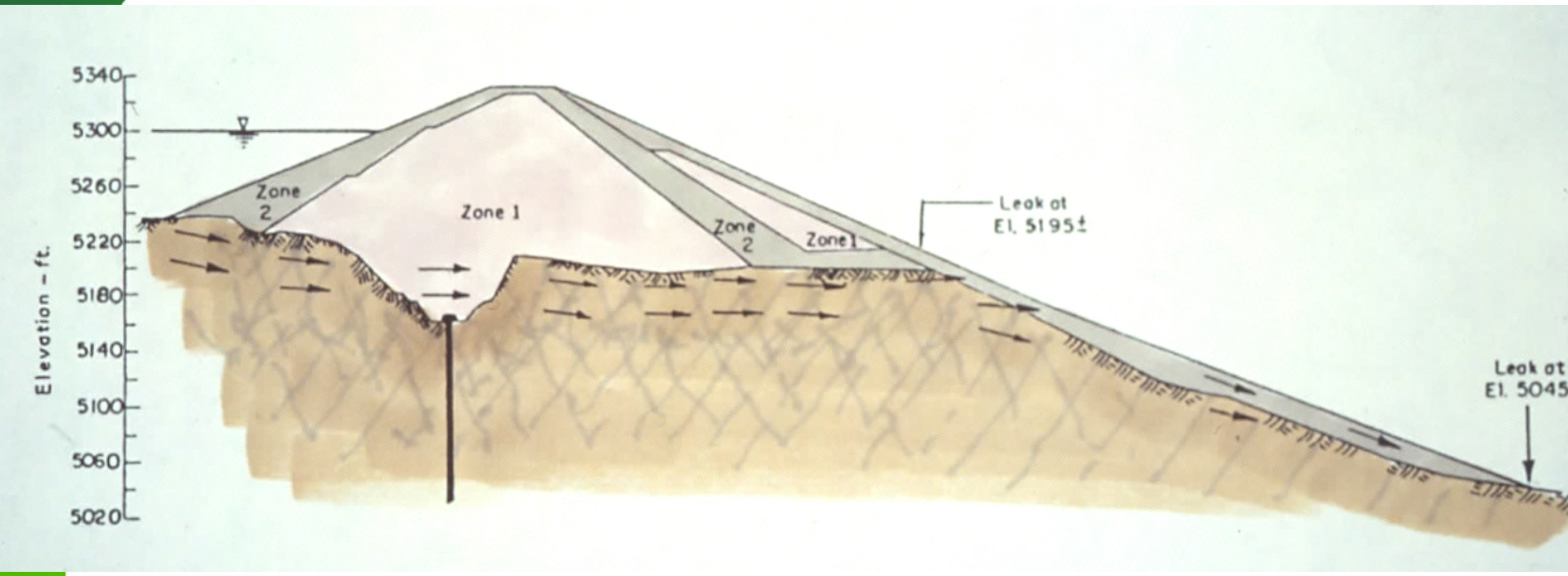


- Detail of right abutment keyway area, showing zone between elevations 5190 and 5230 underlain by blocky Unit 2 rhyolite
- This is the fatal seepage zone, where water appears to have jumped across the keyway, initiating hydraulic piping of the Zone 1 loess fill



- **Cross section of right abutment keyway and crest embankment where the keyway trench was between elevations 5165 and 5220. The hydraulic piping appears to have initiated at this elevation in the keyway, based on observations the morning of the failure.**

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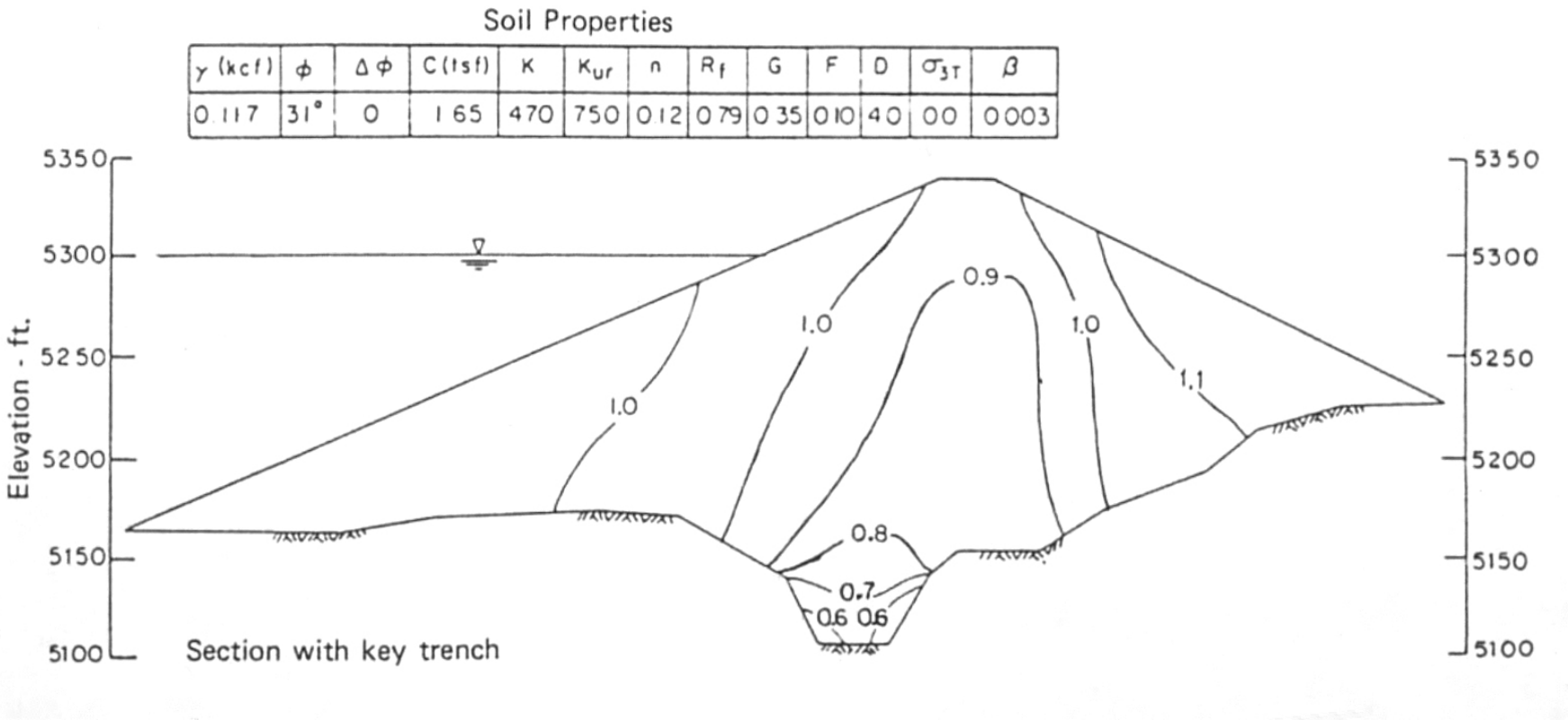

- **Results from finite element analyses at U.C. Berkeley showing contours of ratio between vertical stress in embankment to overburden pressure in the keyway trench at Sta. 15+00, before wetting of the loess fill. The analysis suggests the load of the embankment was being arched across the steeply-inclined keyway trench.**

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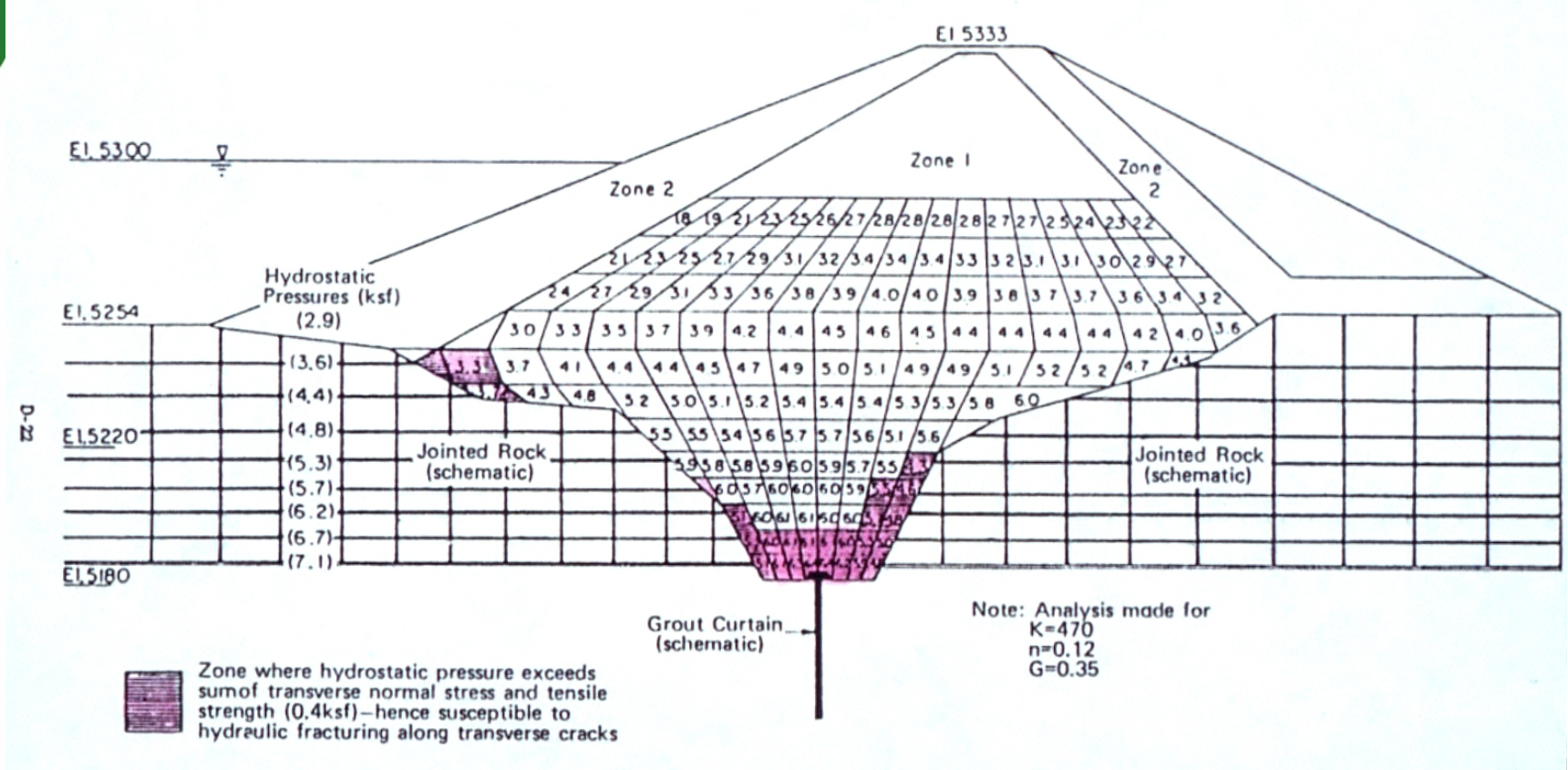

- **Computed values of normal stress on cross section of right abutment at Sta. 13+70. The highlighted areas are where the predicted hydrostatic pressure exceeds the sum of the transverse normal stress and tensile strength of the Zone 1 fill. These zones would have been susceptible to hydraulic fracturing.**

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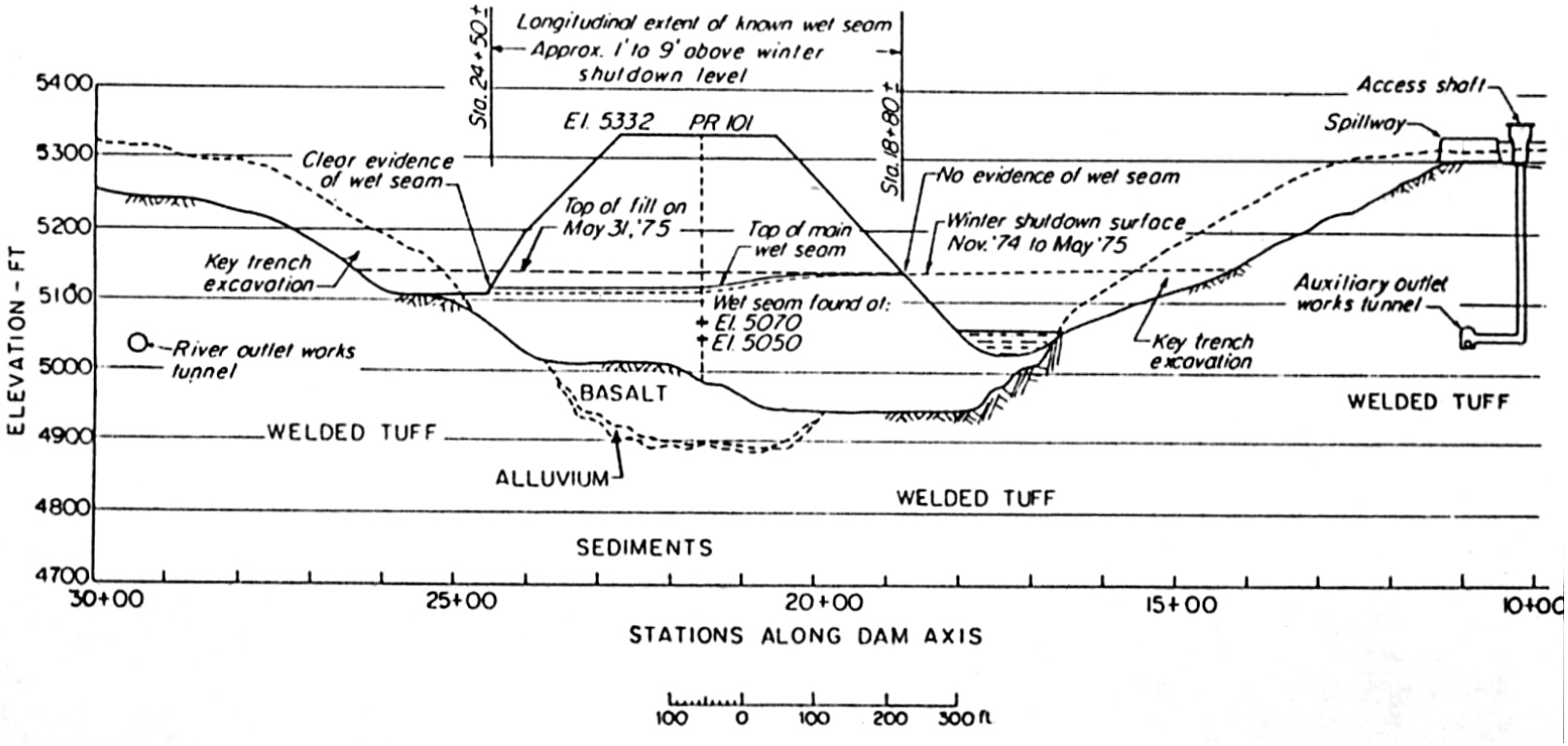
POST-MORTEM ANALYSES



- **In 1977 the Bureau of Reclamation dissected the remaining embankment and unearthed the left abutment keyway to examine the embankment fill and abutment contacts**

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- This shows the enormous cut severing the left side of the main embankment fill, exposing the inclined Zone 2 gravel drain. This is how the dam appears today.

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- View looking downstream in 1977, after channelization of the outbreak flood debris choking the channel.

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- **Ririe Dam was built by the Walla Walla District of the Corps of Engineers in an adjoining watershed with near-identical geology - at the same time as Teton. It did not fail. Why?**

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CONCLUSIONS

- Teton Dam was constructed with numerous shortcomings, any number of which may have combined to cause its untimely demise during its initial filling. These deficiencies include:
- Inadequate grout curtain;
- Lack of filter or sealer between core loess and open fractures in abutments;
- Excessively steep side walls in abutment keyways, promoting arching and likelihood of hydraulic fracturing;
- Gross inconsistencies in compaction techniques and soil conditioning (wet seams) which may have led to asymmetric hydrocompaction, which could have caused open voids to form in the abutment keyway.

CONCLUSIONS

- A calculated Factor of Safety less than 1.0 does not, in of itself, mean that a structure failed via the precise mechanism analyzed.
- All manner of failure mechanisms should be evaluated without prejudice. This is difficult to do, for we are all prejudiced by our life's experiences.

Acknowledgements

H. Bolton Seed

J. Michael Duncan

Richard E. Goodman

Ralph B. Peck and the presenter

I began working on the Teton Dam failure during grad school at U.C. Berkeley (1976-82), because Professor Harry Seed was appointed to the Independent Panel to Investigate the Failure. He asked me to make a detailed review of the construction records. The analyses of the stresses in the right abutment keyway and the likelihood of hydraulic fracturing were supervised by Professor Mike Duncan. I also worked with Professor Dick Goodman performing simulated hydraulic piping of the loess through fractures in the fractured rhyolite. 20 years later, I began a series of interviews with Professor Ralph Peck, upon which this lecture is based. Peck was also a member of the Independent Panel to Investigate the Failure.

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